Computational Fluid Dynamics in Building and Duct Design

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July 18, 2001

2001 National Workshop on State Building Energy Codes

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Outline

- CFD 101
- CFD Modeling Examples
- Residential Heating Application
- Summary

What is CFD?

- **Computational Fluid Dynamics (CFD)**
  - Numerical solution of the governing equations of heat and mass transfer; i.e., Computer Simulation

$$\Gamma \frac{\partial}{\partial t} \iiint \boldsymbol{Q}\, dV + \iint \left[\vec{\boldsymbol{F}} - \vec{\boldsymbol{G}} \right] \cdot d\vec{A} = 0$$

  - Conservation of Mass, Momentum, Energy

CFD in the Hands of the Designers

- **Until Recently CFD was reserved for the “high-tech” industries such as aerospace and power generation.**
  - Increased computer power has made CFD into a viable design tool for many industries.
- **CFD Output:**
  - Prediction of all flow variables at all points in the flow domain: pressure, temperature, velocity, …
  - Calculation of IAQ variables, %RH, PPD, PMV
  - Quantitative results: pressure loss, velocity profiles, system loads, ...

Uses for CFD in HVAC and Building Design

- **Proof of Concept for New Design Ideas**
  - Get it right the first time
- **Troubleshooting of Existing Designs**
  - Highlight the CAUSE, not just the EFFECT.
- **Minimize Risk**
  - Verify designs that are beyond the scope of traditional design methods
- **Optimization of equipment sizing**
  - Improved efficiency
  - Reduced Operating Costs
  - Energy Savings from Improved Designs

CFD in the Commissioning Process

- **Design Phase**
  - Verify design concepts
  - Optimize HVAC Layout Sizing
  - Examine “What-If” Scenarios
  - Environmental Impact
  - Ensure Proper IAQ/Comfort Levels
- **Building Phase**
  - Examine Design Changes
  - Troubleshoot
- **Compliance**
  - Complement Compliance Testing

CFD Duct Analysis: k-Factors*

- **Experimental and Computational Analysis**
- **CFD used to examine the effect of the interaction between fittings.**
  - **Elbows**
  - **Mitered Square Bends**
  - **Transitions**
  - **Dampers**
  - **Constrictions**
  - **Junctions**

Composite Mitered Square Bends

# of Bends x Angle	Predicted	ASHRAE(1989)	Miller (1971)
1 x 90	1.3	1.2	1.2
2 x 45	0.32	0.34	0.35
3 x 30	0.24	0.27	0.33
4 x 22.5	0.21	0.244	0.20

$$k = \frac{\Delta p}{\frac{1}{2}\rho v^2}$$

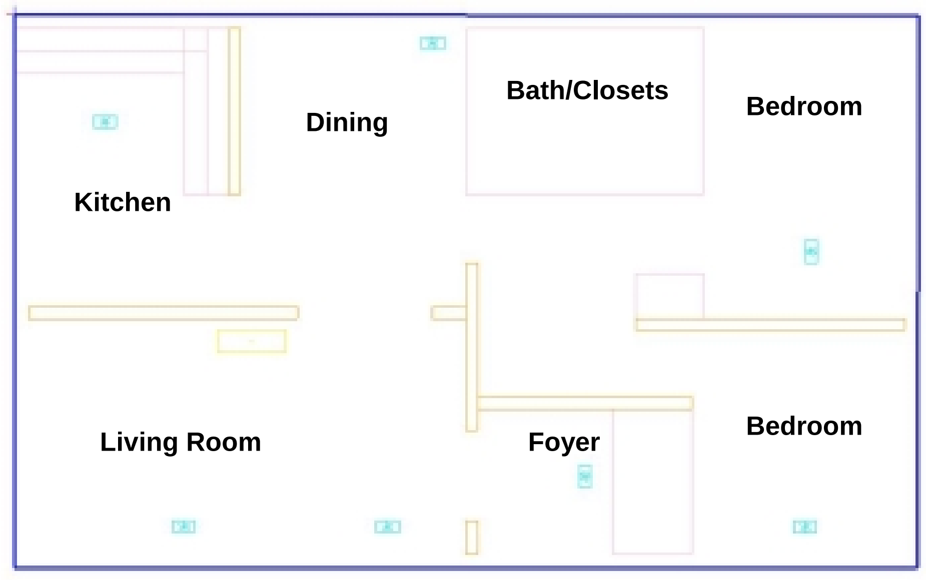
*** Reference: Gan G., Riffat S. B., Smith, S. J., & Shao, L., "Determination of k-factors for HVAC System Components," CIBSE Conference, 1997.**
ASHRAE, Handbook of Fundamentals, 1989.
Miller, D. S., "Internal Flow - A Guide to Losses in Pipe and Duct Systems," BHRA, Cranfield, 1971.

Residential Heating Example

MODELING ASSUMPTIONS

- **Heating Condition:**
  - 30º F outside Temp
  - 68º F initial starting Temp
  - 80º F Supply Air
- **Models:**
  - Sealed
  - 20% Leakage
- **Transient Analysis**
  - T = 10 minutes
  - Δt = 0.2 seconds
- **Steady State Analysis**
- **Numerical Modeling**
  - Indoor Zero-Equation Turbulence Model
  - Conduction Through Walls

Floor Plan: 2-bedroom Single Family Residence



Reference: Burroughs, H. E., Kinzer, K. E., & Gonsoulin, T., "Improved Filtration and the Residential Environment: An Intervention Research Project to Determine the Relevancy and Efficacy of Particulate Filtration in Improving Air Quality Conditions in Residences," ASHRAE IAQ and Energy 98, Using ASHRAE Standards 62 and 90.1, New Orleans, Oct. 1998.

Summary

- The power of CFD is now available for the HVAC Design Engineer as a practical design tool
- Detailed CFD analysis of HVAC components, such as complicated duct analysis can aid in the design process.
- CFD can be utilized in the Commissioning process for validation of design features.
- Effect of design changes and performance degradation can be assessed in terms of excess energy usage and comfort levels.